

AIRPORT NOISE IMPACT REDUCTION THROUGH OPERATIONS

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SUMMARY

The objective of Langley Research Center's airport community noise impact modeling program is to develop the technology for noise impact assessment and minimization in airport communities. Focus for this program is an airport community computer simulation model called ALAMO (Airport-noise Levels and Annoyance M0del) which is capable of overlaying distributions of aircraft noise level (footprints) on the population distributions of any U.S. airport community. Recently developed psychophysical relationships between noise exposure level and subjective response are then invoked to predict the overall impact of airport noise on the surrounding community, based on the number of individuals exposed to various levels of noise. Outputs of the program include a prediction of the number of residents expected to be "highly annoyed" with the airport noise, as well as several demographic variables listed as a function of noise level, including population, population density, and population growth rate. The ALAMO model can be used to quantify the degree of noise impact reduction which can be achieved by various candidate noise abatement strategies. For example, a number of runway selection alternatives might be compared with the imposition of a night curfew to see which strategy results in the greatest reduction of highly impacted residents. In a similar manner, various fleet mix and land-use alternatives can be assessed to determine which has the greatest potential for alleviating noise impact. Since each noise abatement strategy will have a cost associated with it, the ALAMO model can be used to determine an appropriate distribution of limited airport noise abatement resources.

In this paper, the effects of various aeronautical, operational, and land-use noise impact reduction alternatives are assessed for a major midwestern airport. Specifically, the relative effectiveness of adding sound absorbing material to aircraft engines, imposing curfews, and treating houses with acoustic insulation is examined.

INTRODUCTION

Concern for the impact of noise on airport communities represents a major impediment to the growth and development of commercial aviation, both in the United States and abroad. Noise effects are largely responsible for the fact that, in the United States, no construction has been initiated for new jet airports to serve major metropolitan communities in a decade even though the demand for air transportation has grown dramatically in the same period.

Figure (1) illustrates the growth in passenger-km/yr (mi/yr) in the United States since 1950, with the current trend extrapolated to 1990 (ref. 1). The increased demand for air carrier service has been partially absorbed through increased operations at established airports. Residents of the more severely impacted airport communities have organized themselves politically in order to impose various noise abatement operating constraints on the airports serving their communities. Figure 2 illustrates the trend toward increased operating constraints at airports worldwide. If the historical trend of increasing air carrier demand continues as expected, the trend toward more tightly constrained operations can also be expected to continue.

In addition to constraints on airport operating procedures which might take the form of night curfews, takeoff and landing profile restrictions, or restrictions on ground tracks, other abatement countermeasures are also of interest to airport operator and community planners. These nonoperational countermeasures can be classified as either aeronautical countermeasures or land-use countermeasures. Aeronautical countermeasures involve the development and implementation of source noise suppression technology to reduce noise levels emanating from the jet engines. Available technology options include new fan designs, acoustic liners, engine inlet designs, and internal flow mixers (ref. 2). Land-use countermeasures include zoning restrictions to discourage future residential construction in the airport vicinity, relocation of residents out of highly impacted areas, and insulation of impacted homes to provide noise relief.

The task of developing an effective noise abatement strategy is complicated by difficulties in defining quantitatively the degree of noise relief which is afforded by a particular countermeasure. Furthermore, the noise relief which a particular countermeasure provides can be much different for one airport than for another. For example, a takeoff procedure which involves a large cutback in thrust soon after takeoff will provide greater relief in communities with higher population densities near the airport than in communities with higher population densities further from the airport.

This paper describes the implementation of an assessment methodology which permits the quantitative assessment of a variety of noise abatement options on an airport-specific basis. The assessment method, which is implemented in a computerized community response model called the Airport-noise Levels and Annoyance Model (ALAMO), is demonstrated for the case of a major midwestern airport. Several potential aeronautical, operational, and land-use countermeasures are evaluated for this airport.

IMPACT ASSESSMENT METHODOLOGY

The Fractional Impact Method of assessing community response to airport noise is used in the impact assessments described in this paper. This method expresses noise impact in terms of the number of people exposed to noise of a particular level, in the following way: The number of people exposed to a particular noise level is multiplied by a dimensionless weighting function

which depends on that noise level. The weighting function is based on Schultz's relationship between human subjective response to noise (percent "highly annoyed") and noise level as described by the L_{dn} metric (ref. 3). The weighting function is obtained by normalizing the Schultz dose-response transfer function to unity at 75 L_{dn} and represents the "fraction of impact" associated with various noise levels, assuming an impact of 100 percent at 75 L_{dn} (fig. 3). The product of this level-dependent weighting function and the number of people exposed to each noise level is summed for all noise levels in the airport community, resulting in a quantity called the level weighted population, which expresses noise impact in terms of both noise level (intensity) and population exposed (extensity).

Working Group 69 of the National Research Council's Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) developed the level weighted population concept as it is used in this paper and has recommended this concept for quantifying noise impact in their "Guidelines for Preparing Environmental Impact Statements on Noise" (ref. 4), prepared at the request of the Environmental Protection Agency. Also described in reference 4 is a second noise impact descriptor called the Noise Impact Index (NII), which is defined as the ratio of the level weighted population (described above) to the total impacted population. The NII is a useful measure for comparing the noise impact in communities with different numbers of impacted residents.

IMPLEMENTATION OF ASSESSMENT METHODOLOGY

The idea that community response to noise should be described in terms of noise level and population exposed is not new. Early applications of the fractional impact concept are described in reference 5 for example. Even though the basic concept is not new, a practical means for routinely performing fractional impact calculations has had to await three technical developments, two of which have occurred only recently.

The first of these developments has to do with describing noise levels at arbitrary locations within an airport community. Methods for performing this task have been available for several years and involve the combining of aircraft source noise and performance data with noise prediction methodology to generate contours of constant noise exposure around an airport (refs. 6 and 7).

The second technical development to facilitate applications of the fractional impact method involves the recent introduction of census data base management computer programs which provide a cost-effective means of obtaining the demographic information required in fractional impact calculations. Before such census data were available in machine readable formats, the demographic data had to be acquired by tedious manual techniques, which were costly and time consuming. Now the population within a noise contour of essentially arbitrary size and shape can be determined quite easily for any airport community in the United States, with a resolution approaching half a square mile in densely populated areas (ref. 8).

The third and final technical development to facilitate routine applications of the fractional impact method is Schultz's identification of a stable relationship between noise level and human subjective response as described in the previous section. The weighting function used to determine the "fraction of impact" associated with a given noise level is based on this recently developed noise dose-response relationship.

The three major components required to assess airport community noise impact via the fractional impact method, namely, a community noise prediction program, a census data base management program, and the Schultz dose-response transfer function, have recently been incorporated into an airport community noise impact assessment model called ALAMO (Airport-noise Levels and Annoyance M0del) (ref. 9). The ALAMO is a computerized implementation of the fractional impact method which can be used to assess noise impact for any airport community in the United States. (Assessments are limited to U.S. airports only because the demographic data base built into ALAMO is based on U.S. census data.) ALAMO reports the number of people impacted as a function of noise level, the number predicted to be "highly annoyed" (via the Schultz dose-response transfer function), the level weighted population and the Noise Impact Index. In addition, complete demographic profiles are generated which contain several quantities of interest to noise control planners, such as distributions of age, property values, homeowners, renters, single-family dwellings, and apartment buildings. Other demographic variables are also available which, while not of direct interest in a noise impact analysis, may provide insight into the prevailing attitude of the impacted population toward the airport. Family income, ethnic origin, occupation, and educational level are examples of such variables. ALAMO generates reports which display demographic variables and the results of noise impact calculations as a function of noise level for the community as a whole and for each of eight octants defined by superimposing an octant compass rose over the noise footprint, centered at the airport. Thus, it is possible to determine the numbers of residents living to the north-northeast of the airport who own their own homes and who are exposed to noise levels between 60 and 65 L_{dn} , for example.

The ALAMO has recently been used to assess both the current operating scenario and a number of hypothetical noise abatement scenarios at an existing large airport. Results of this assessment are presented in the next section.

Baseline Operating Scenario

Most of the operations information upon which the impact assessment in this example is based can be found in draft and final Environmental Impact Statements for the airport (refs. 10 and 11), required because of plans to extend its two major parallel runways. Operations information found in the EIS was augmented by information obtained from current flight schedules and from discussions with control tower personnel at the airport.

The ALAMO requires that the operating scenario for the airport under study be described in terms of four types of information: runway descriptions;

takeoff and landing profile descriptions; ground track descriptions; and descriptions of the operations schedule in terms of the number of operations by aircraft type, time of day, stage length (for takeoffs), ground tracks, and profiles. The runway descriptions are straightforward and simply involve recording the length and orientation of each of the runways. These data were obtained from the Airport Layout Plan (ref. 10) (fig. 4). The takeoff profiles for this airport were modeled after recommendations in FAA Advisory Circular 91-39 (ref. 12) which defines a standard takeoff procedure calling for a reduction from takeoff thrust to maximum climb thrust before flap retraction (cleanup). Ground tracks presented in the draft EIS (ref. 10) were used in the present impact assessment (fig. 5).

The ALAMO requires that flight operations be defined in terms of the number of operations of each aircraft type which occur on each ground track as a function of time of day (day or night) and stage length. The EIS did not contain operations data with quite this level of detail, although enough information was provided to develop an approximate model of the operating schedule, with augmentations from airline flight scheduling information. Percentage use rates given in the EIS for each ground track were multiplied by the number of daily operations given for each aircraft type in order to define the number of each aircraft type to assign to each track. These per track operations were further divided into day (7 a.m. to 10 p.m.) and night (10 p.m. to 7 a.m.) operations according to the following distribution, given in EIS:

	<u>Day</u>	<u>Night</u>
Air Carrier	90%	10%
Commuter	68.9%	31.1%
General Aviation	93.4%	6.6%

Stage length distributions for departing aircraft were not given in the EIS, but estimates were made of the number of departures by stage length based on airline scheduling information (ref. 13). A percentage distribution of takeoff operations by stage length was constructed from this information and applied to the per track day and night operations, with alterations to insure that aircraft types with takeoff roll lengths too long to use other runways were assigned to the longest runway. The results of this operations definition exercise was a table of the number of each aircraft type assigned to each ground track as a function of time of day and takeoff stage length.

Result of the Baseline Impact Assessment

Demographic reports and fractional impact reports were produced for the airport community as a whole and for each of the eight octants around the airport defined by overlaying an octant compass rose, centered on the airport. The compass rose thus divided the community into the north-northeast (NNE), east-northeast (ENE), east-southeast (ESE), south-southeast (SSE), south-southwest (SSW), west-southwest (WSW), west-northwest (WNW), and north-

northwest (NNW) octants. Figure 6 presents the number of people exposed to airport noise levels in excess of $55 L_{dn}$, and includes the level weighted population and the number of people predicted to be highly annoyed by the aircraft noise, all as a function of community location, by octant. Figure 7 presents the corresponding Noise Impact Index and percent highly annoyed data. It is interesting to note that the octants which are most severely impacted (west-southwest and north-northwest) contain the fewest people. This suggests that either the airport noise distribution affects the population distribution around the airport, with fewer people choosing to live in the higher impacted areas, or that the current airport flight tracks avoid the most populated areas.

Figures 8 to 10 illustrate how population density, population growth rate, and average home values vary as a function of noise level in the airport community. The population density data are based on 1977 population figures and the growth rate data represent average annual percentage growth rates from 1970 to 1977. The average home value figures are from 1970 census data. The precision of these demographic data can be questioned because of the assumptions which must necessarily be made about the aircraft and airport operating scenario when computing the noise contours used to bound the airport community residents counted in these data. Furthermore, the average home values presented in figure 10 represent 1970 price levels, which are not relevant today. However, it is the trend of the data that is of interest, rather than the absolute values of the numbers.

The data in figure 8 indicate a maximum population density in the 65 to $70 L_{dn}$ band, with a decrease in population density both as the airport is approached (increasing noise levels) and as the distance from the airport gets larger (decreasing noise level). This is consistent with a general trend reported in ref. 14 for airport communities of this size.

The growth rate data in figure 9 indicate a general decline in the population residing inside the $55 L_{dn}$ contour. While the growth rate is negative for all the noise bands presented, the trend is for a greater decline in population in the higher impacted neighborhoods than in neighborhoods receiving less impact.

Average home values also exhibit a declining trend with increasing noise level (fig. 10). It should be noted, however, that trends in such parameters as average home values and population growth rate should not be associated exclusively with the influence of airport noise since many other factors of course play a role in determining these trends.

EVALUATION OF HYPOTHETICAL NOISE IMPACT COUNTERMEASURES

The previous section presented the results of a noise-impact assessment based on a model of the current operating scenario at a large midwestern

airport. It is not necessary to limit such an assessment exercise to the current operating scenario, however. Alternate scenarios, including those which may have the potential for reducing noise impact, can be modeled as well. The relative effectiveness of several hypothetical noise abatement strategies can thus be readily determined. A number of such noise abatement countermeasures have been modeled and are presented in this section.

Description of Countermeasures

Seven noise abatement countermeasures which were modeled are described in this section. These include two aeronautical countermeasures, two operational countermeasures, two land-use countermeasures, and one combined aeronautical/operational countermeasure.

The first noise abatement scenario to be considered consisted of treating the engines of narrow-body jet transports with sound absorbing material (SAM treatment). This countermeasure was implemented by replacing the standard 727, 737, DC-9, 707, and DC-8 noise curves which reside in the data base of the ALAMO noise prediction subprogram with resident noise curves describing SAM-treated engines. It should be noted that as older, noisy aircraft are retired from the fleet, the fleet mix which evolves will contain a progressively larger fraction of aircraft which are powered by quieter engines, and the attractiveness of this engine modification alternative will, therefore, diminish with time. It is interesting, nonetheless, to compare this source-noise countermeasure with operational and land-use alternatives.

The second scenario consisted of diverting all general aviation aircraft to alternate airports. While it is recognized that such a policy would be impractical to implement, it is nonetheless of interest to assess the relative contribution of general aviation operations to the total airport noise impact.

A night curfew was modeled, in which all of the operations scheduled after 10 p.m. were rescheduled before 10 p.m. This case was run a second time, with the night curfew applied only to scheduled operations.

In the fourth scenario, all aircraft were modeled as landing further down the runway than in the baseline case, in which the landing threshold was modeled at 1000 feet from the end of the runway. This displaced threshold countermeasure is of particular interest since it has in fact been implemented at JFK International Airport for Concorde SST approaches. Two threshold displacements were modeled, 1000 feet and 2000 feet.

Two land-use countermeasures were modeled: vacating the $75 L_{dn}$ contour and insulating all homes inside the $65 L_{dn}$ contour to provide the equivalent of a 6 dB reduction in noise level. In the first land-use scenario, all residents inside the $75 L_{dn}$ contour were presumed to be relocated completely outside of the airport community and were neglected in the ensuing fractional impact calculations. In the second land-use scenario, 6 decibels were

subtracted from all the contour values inside the 65 dB contour prior to performing the fractional impact calculations.

The final countermeasure to be modeled consisted of a combination of two of the countermeasures previously described. This case modeled both a night curfew and all narrow-body jet transports treated with sound absorbing material.

Besides the seven noise abatement countermeasures described above, one additional case was run which, while not a countermeasure option, is of interest nonetheless. In this case, all operations were doubled in order to assess the noise impact which such an increase in operations might have, assuming no change in the population distribution modeled in the baseline case.

Noise Effect of Alternative Airport Community Scenarios

The number of community residents predicted to be highly annoyed was calculated for each of the alternative airport community scenarios described in the previous section, and compared with the number predicted to be highly annoyed under the current scenario. The percentage reduction in population highly annoyed was then calculated in order to assess the relative effectiveness of each of the hypothetical noise abatement countermeasures. These calculations were performed for each of the eight compass rose octants around the airport, as well as for the community as a whole, and the results are presented in figures 11 to 18 and summarized in Table I.

TABLE I.- IMPACT COUNTERMEASURE EFFECTIVENESS

COUNTERMEASURE	REDUCTION IN ANNOYED POPULATION
SAM Engine Treatment	43%
Curfew - All Operations	30%
Curfew - Scheduled Operations	29%
House Treatment Inside 65 L _{dn}	26%
Vacate 75 L _{dn} Contour	4%
Ban All G/A Operations	2%
1000 Ft. Displaced Landing	2%
2000 Ft. Displaced Landing	1%
SAM + Curfew	68%

The most effective individual countermeasure modeled was to treat the aircraft engines with sound absorbing material. A 43 percent reduction in population highly annoyed is predicted. Next in predicted effectiveness is to impose a night curfew so that all operations after 10 p.m. are rescheduled for before 10 p.m. This noise abatement strategy is predicted to result in a 30 percent reduction in highly annoyed population. Restricting the curfew to scheduled jet transport operations was found to be almost as effective,

with a 29 percent reduction in the most severely impacted residents. Treating houses inside the existing $65 L_{dn}$ contour with sufficient noise insulation to result in an effective L_{dn} reduction of 6 dB is predicted to cause a 26 percent reduction in highly annoyed population. The remaining individual countermeasures, banning G/A operations, using displaced landing thresholds, and relocating residents who live inside the $75 L_{dn}$ contour, were found to have a relatively small (1 percent to 4 percent) effect on the number of highly annoyed residents. When the two most effective countermeasures (SAM engine treatment and night curfew) were combined, the reduction in highly-annoyed population was found to be 68 percent, compared with 43 percent and 30 percent respectively, for the two countermeasures applied separately.

The data in Table I refer to the effects of various countermeasures on the airport community as a whole, while figures 11 to 18 indicated, in addition, the impact in each of the octants surrounding the airport. It is interesting to note that there is a relatively wide variation in the degree of relief associated with each countermeasure from octant to octant. For example, while providing acoustic insulation for homes inside the $65 L_{dn}$ contour is predicted to result in a community-wide reduction in noise impact of 26 percent, the noise impact reduction is predicted to vary from as little as 10 percent to the south-southwest of the airport, to as much as 38 percent to the north-northwest. These differences in the degree of impact reduction achievable in different areas of the same airport community are attributed to the nonuniform nature of both the noise and population distributions. Such differences in impact by area within the community are especially interesting for countermeasures such as insulating homes, which can be carried out in selected neighborhoods when limited noise abatement resources preclude applying the countermeasure to the airport community as a whole.

In addition to investigating potential noise abatement countermeasures, the noise impact of doubling the number of operations was also calculated (fig. 18). Noise impact is not a linear function of the number of flight operations, since doubling all operations increased the noise impact by a factor of only 1.5.

CONCLUDING REMARKS

The noise impact of current flight operations has been modeled for a major airport using the Fractional Impact Method, and predictions of the number of residents highly annoyed with aircraft noise have been made based on a recently-developed psychophysical relationship between noise level and human subjective response to noise. A number of aeronautical, operational, and land-use noise impact countermeasures were also modeled to assess their relative effectiveness in reducing the current noise impact.

Source noise reduction was found to be the most effective noise impact countermeasure (43 percent reduction in highly annoyed population), while

banning night flights and insulating homes inside the 65 L_{dn} contour were also found to be effective (30 percent and 26 percent reduction in highly-annoyed population, respectively). Other countermeasures, such as displaced landing thresholds, diverting G/A aircraft, and relocating residents who live inside the 75 L_{dn} contour, were found to have a small (less than 4 percent) effect on the number of highly-annoyed airport community residents. Doubling the number of operations was found to increase the noise impact by a factor of 1.5.

The results obtained for this airport illustrate the potential effectiveness of various aeronautical, operational, and land-use noise-impact countermeasures which might be applied to a commercial jet airport. The specific results reported here apply only to the airport which was selected for analysis; other airports, with different noise and population distributions, may yield different results. In particular, the rank-ordering of countermeasures by effectiveness may vary from airport to airport, and general conclusions about the relative effectiveness of a particular countermeasure must be preceded by an analysis of more airports. The ALAMO community response model used in the present study was designed to facilitate such an analysis and provides a tool for studying the noise effects associated with a wide variety of actual or hypothetical operating scenarios on a site-specific airport community basis.

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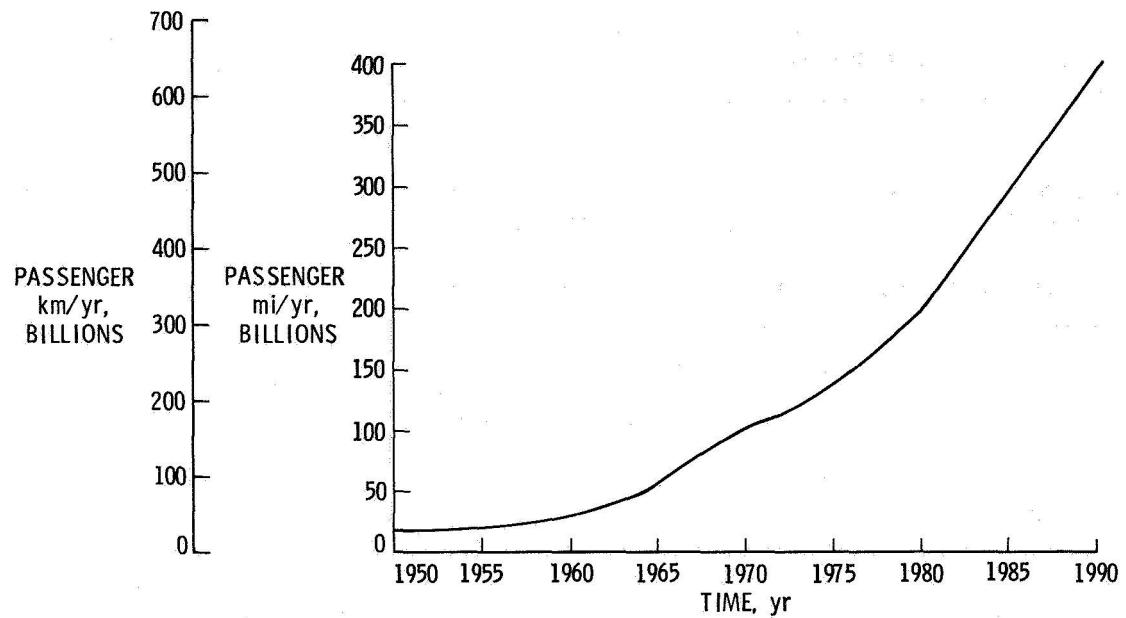


Figure 1.- Growth in U.S. air carrier service.

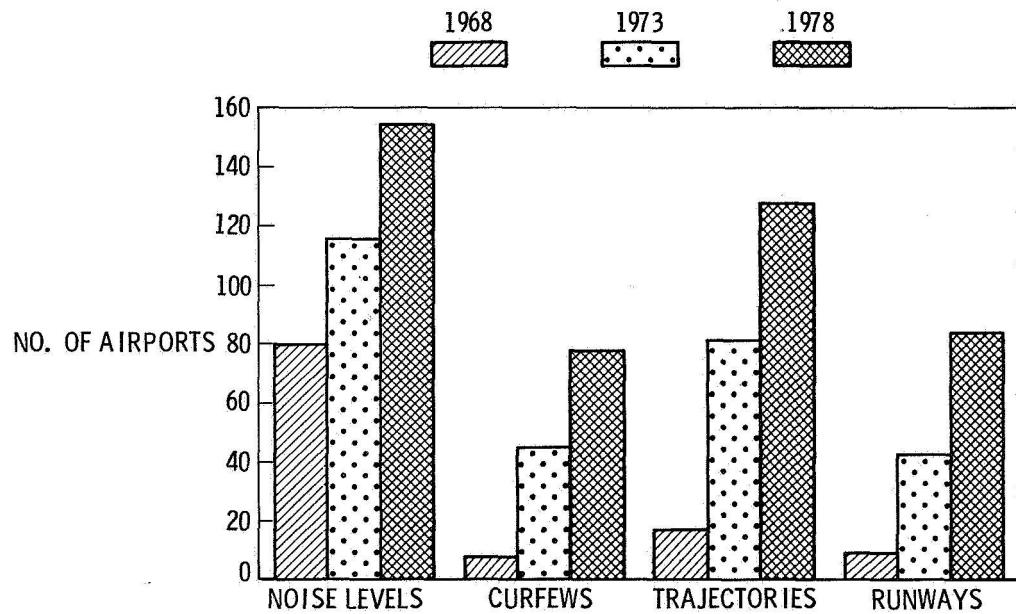


Figure 2.- Noise constraints at major world airports.

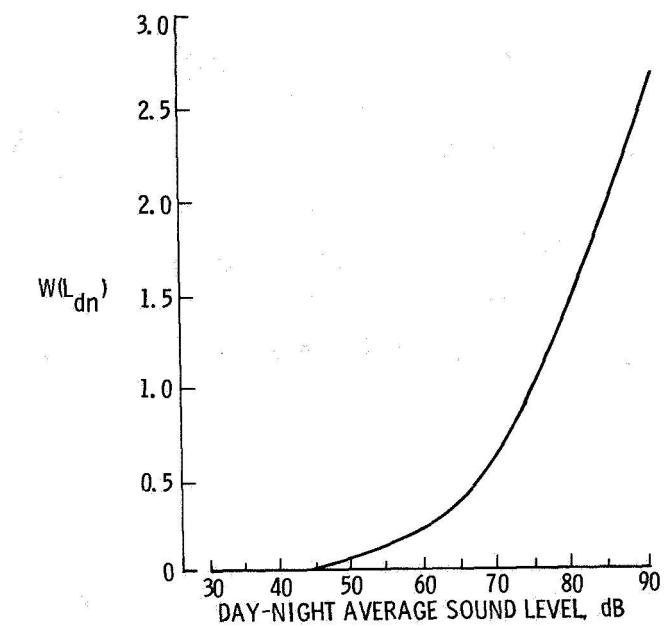


Figure 3.- Sound level weighting function (W) for fractional impact analysis.

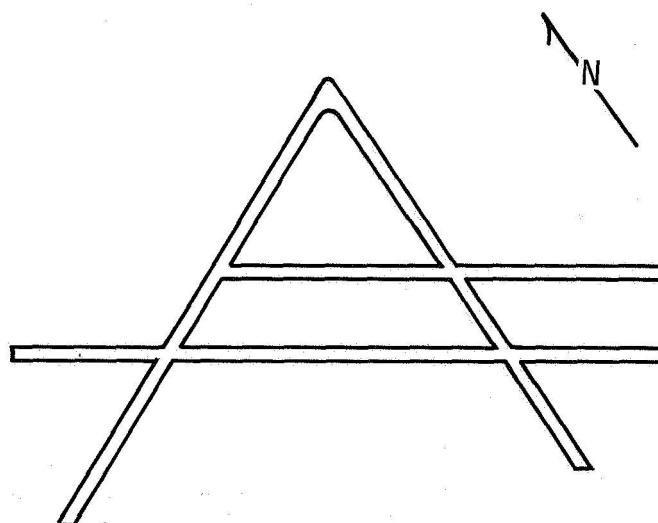


Figure 4.- Runway orientation.

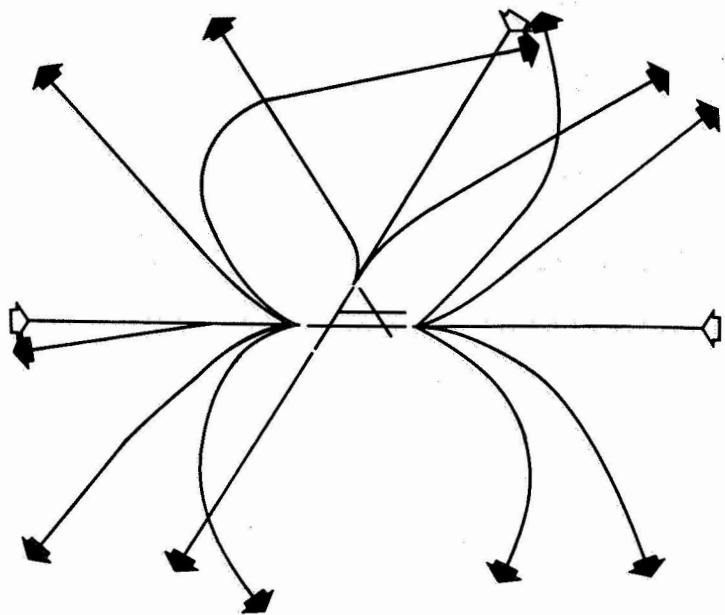


Figure 5.- Ground tracks.

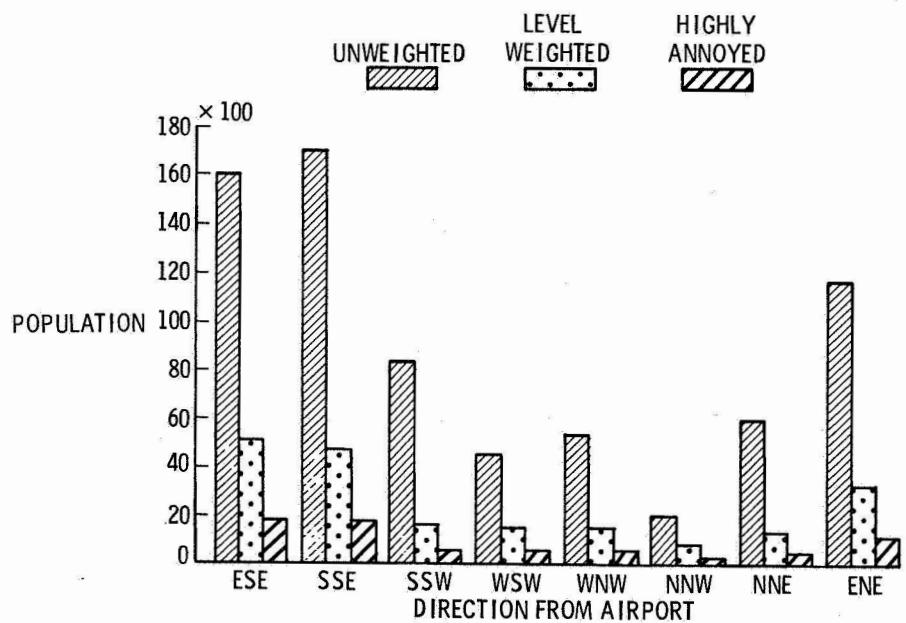


Figure 6.- Noise impact in terms of impacted population.

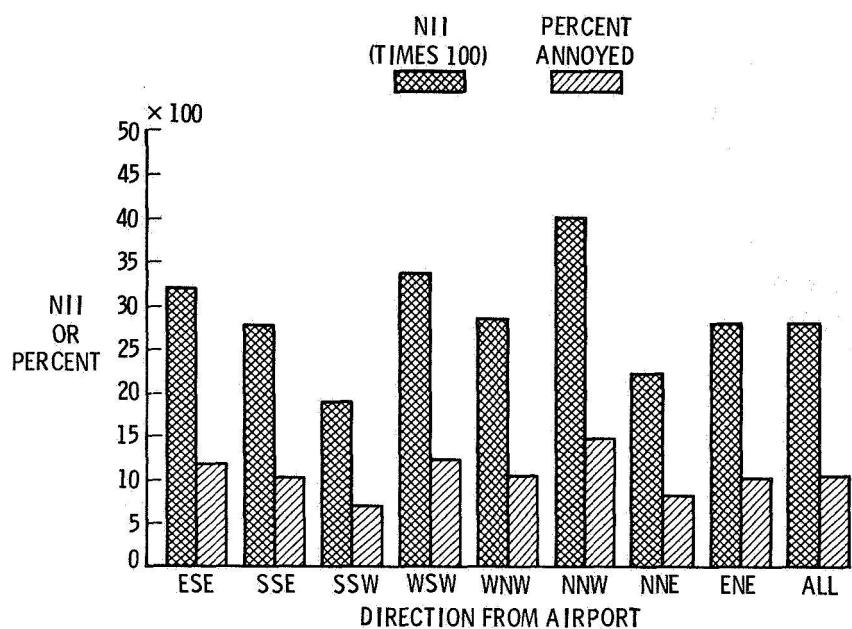


Figure 7.- Community noise impact levels.

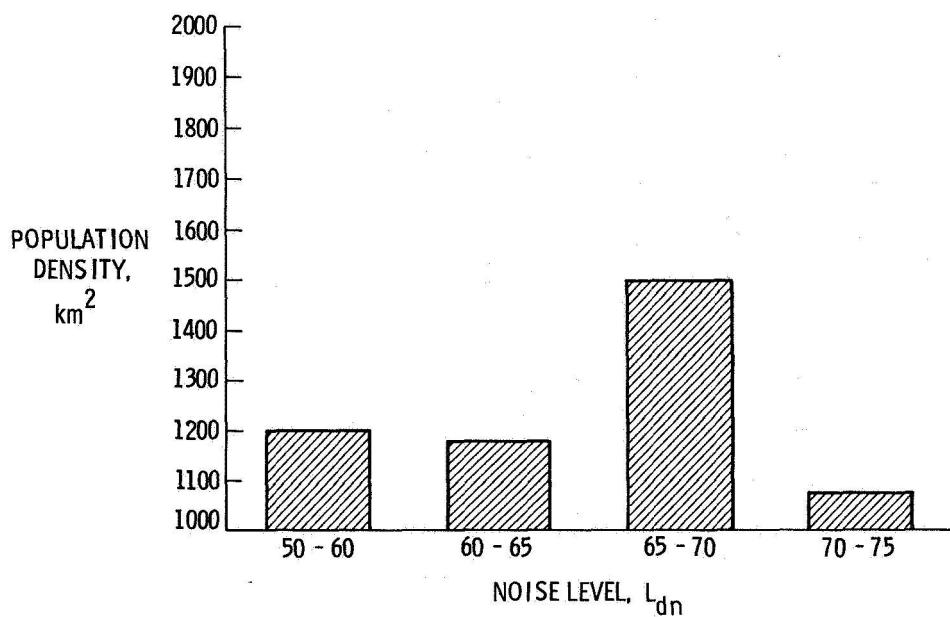


Figure 8.- Population density.

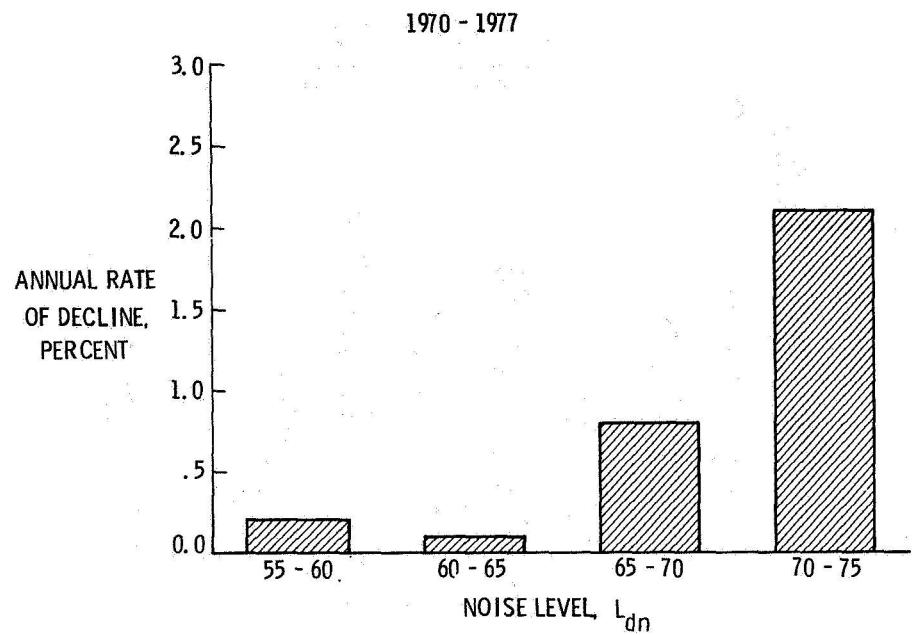


Figure 9.- Annual rate of decline in population.

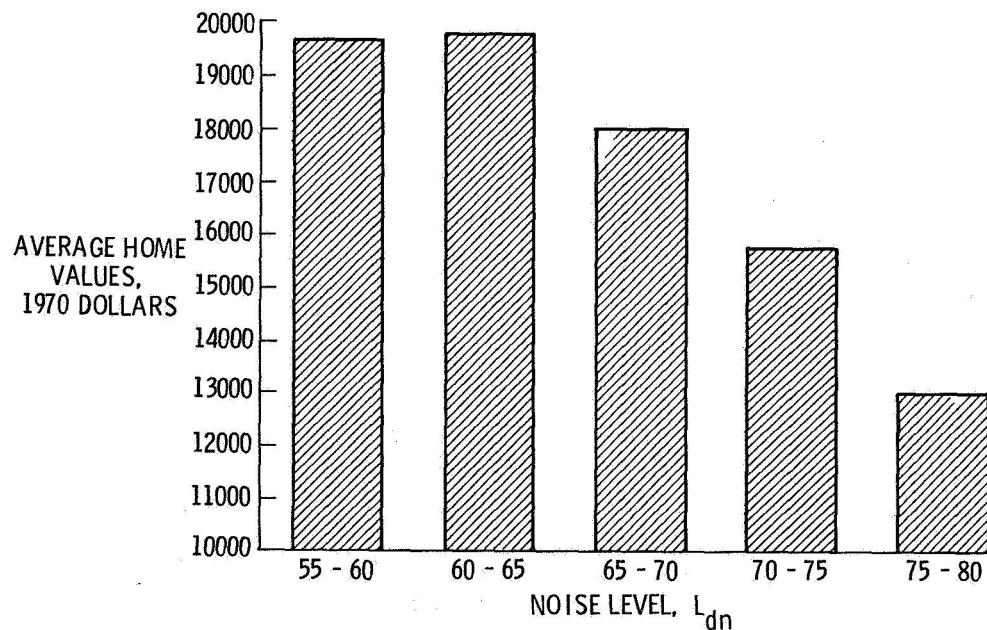


Figure 10.- Average home values.

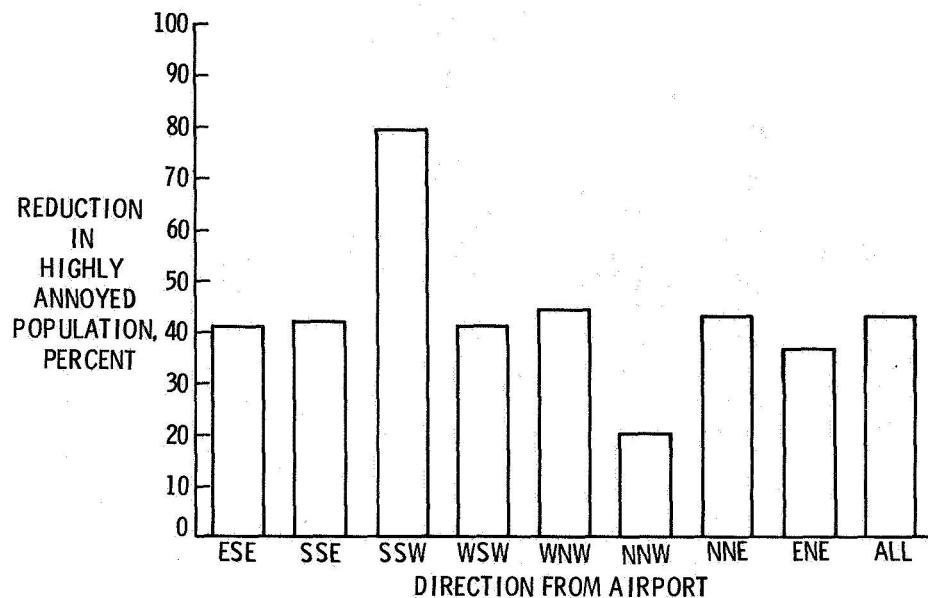


Figure 11.- Effect of adding sound-absorbing material to aircraft engines.

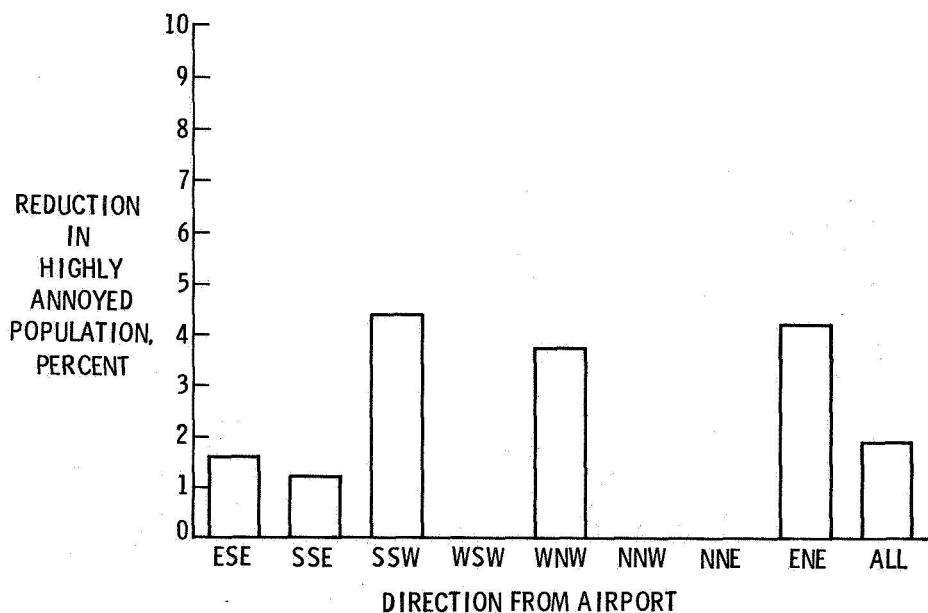


Figure 12.- Effect of eliminating general aviation operations.

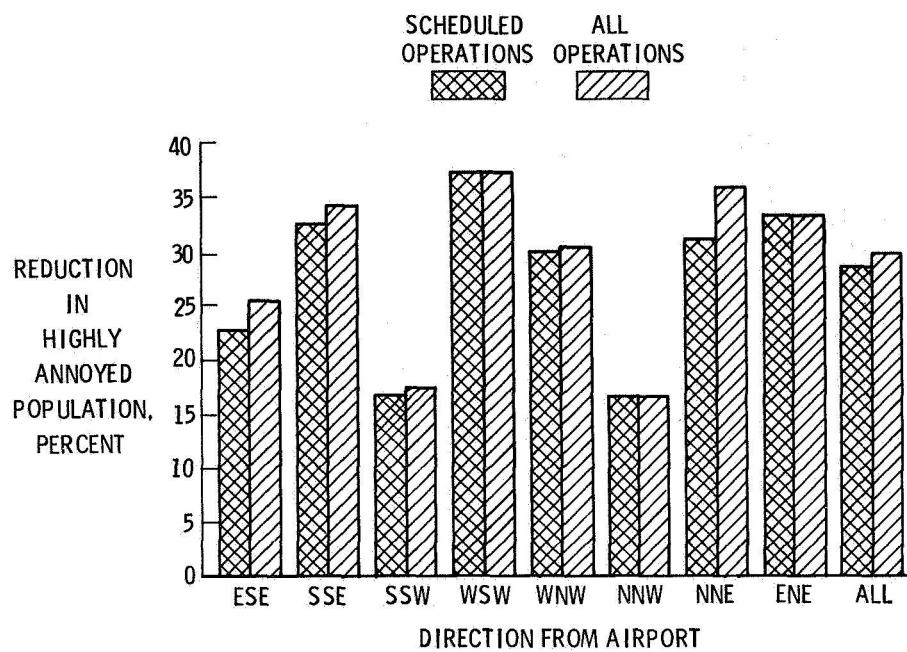


Figure 13.- Effect of imposing a night curfew.

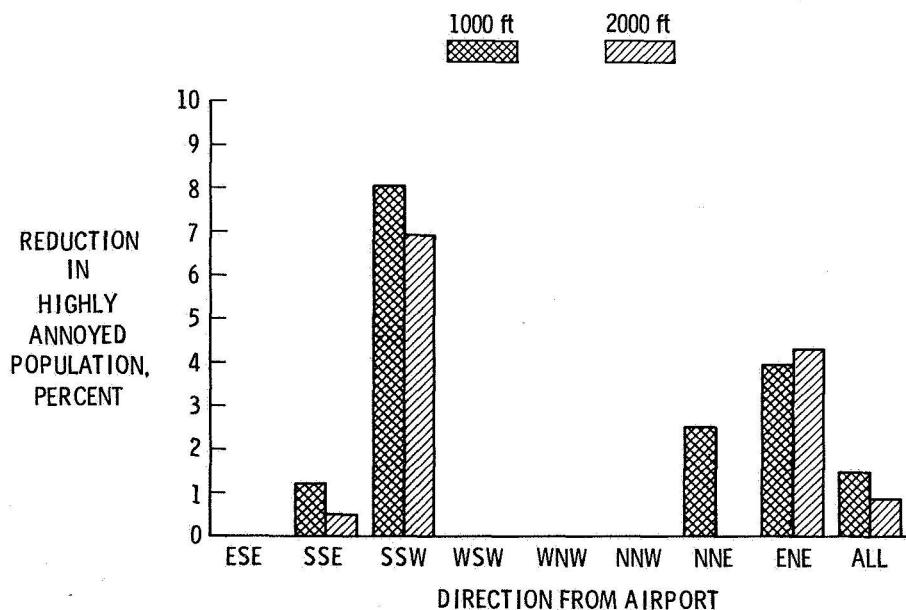


Figure 14.- Effect of displaced landing thresholds.

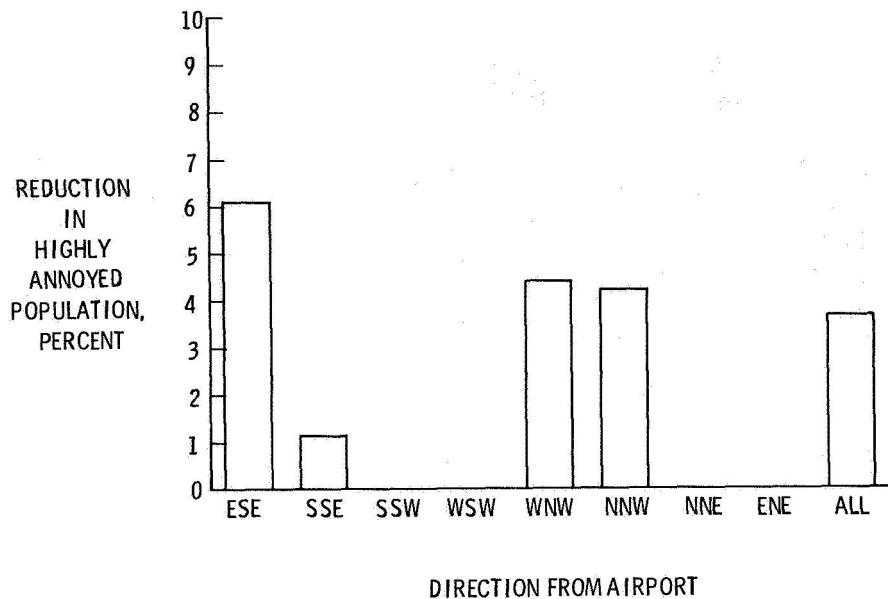


Figure 15.- Effect of vacating 75 L_{dn} contour.

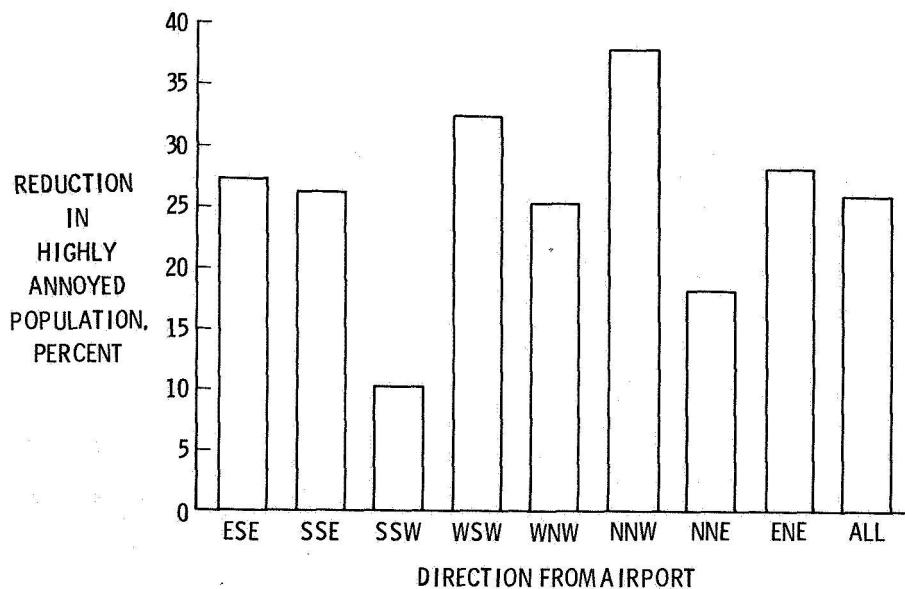


Figure 16.- Effect of a 6 dB acoustic treatment for homes inside 65 L_{dn} .

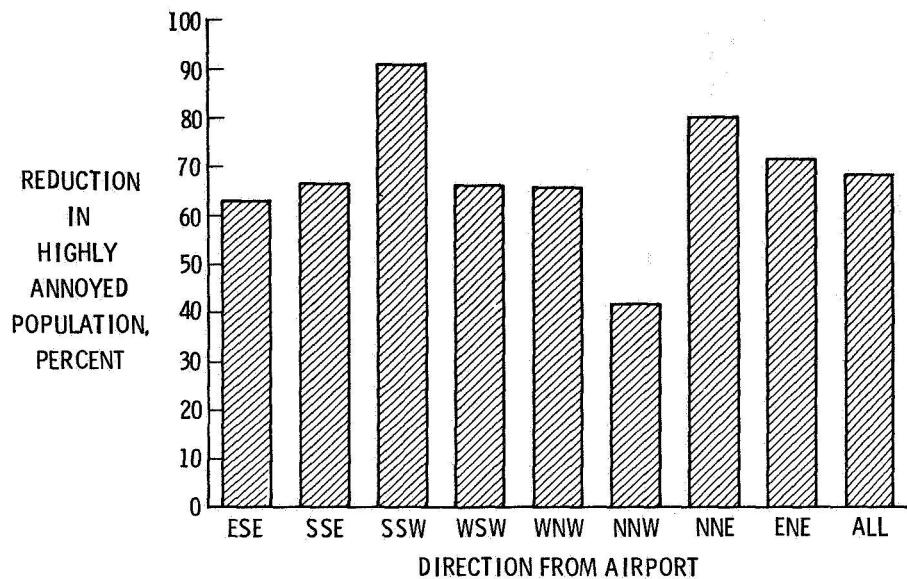


Figure 17.- Effect of sound-absorbing material plus night curfew.

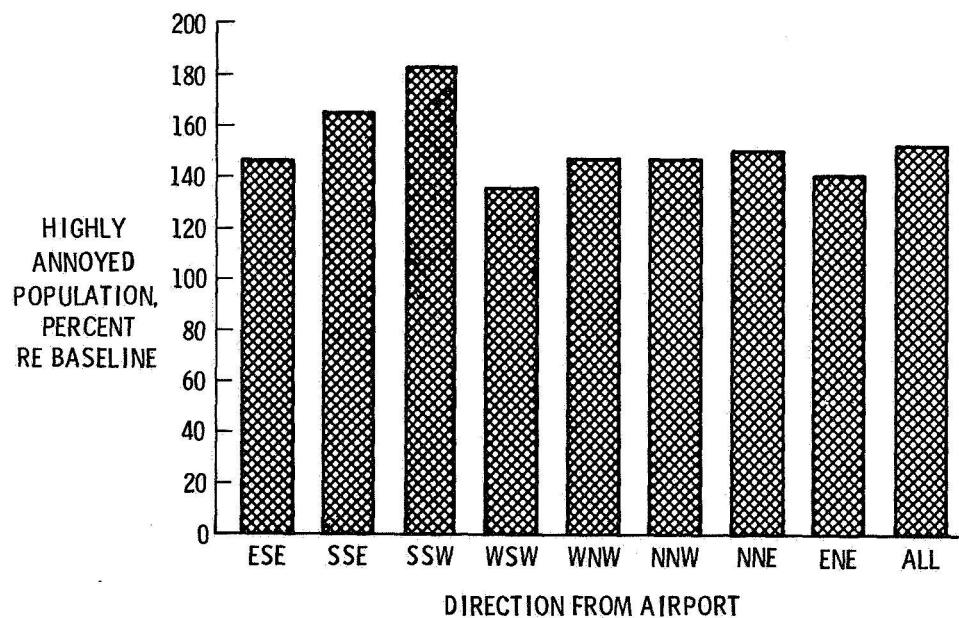


Figure 18.- Effect of doubling the number of operations.